# eRHIC Machine Plans

V.Ptitsyn

# eRHIC Machine Collaboration

- ### BNL:
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
- ### MIT-Bates :
  M.Farkhondeh, W.Franklin, W.Graves, R.Milner, C.Tschalaer, J.B. van der Laan, F.Wang, D.Wang, A.Zolfagari, T.Zwart

- ### BINP, Russia: A.V.Otboev, Yu.M.Shatunov

- ### DESY, Germany: D.P.Barber

- ### Design areas:
  - MIT-Bates: Electron injector and electron ring development
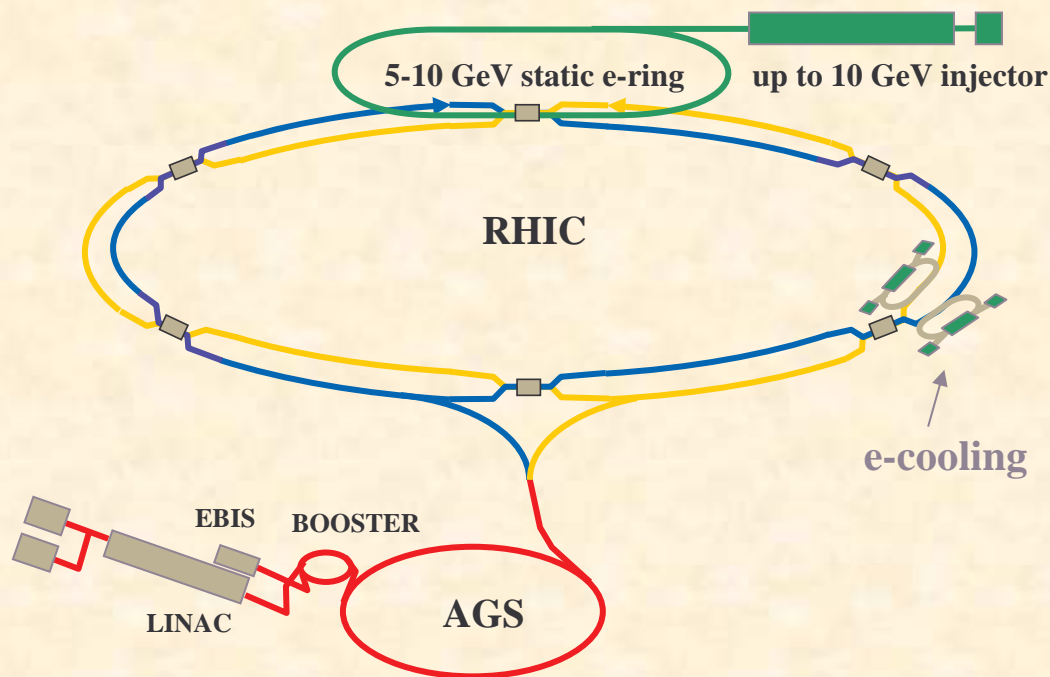  - BNL:          Interaction region and ion ring upgrades

# Project scope and goals

- Experiments with electron-proton and electron-ion collisions.
- Should be able to provide the beams in following energy ranges:
  - 5-10 GeV polarized electrons;
    10 GeV polarized positrons
  - 25-250 GeV polarized protons;
    100 GeV/u gold ions
- Other ion species, especially polarized $^3$He ions are under consideration.
- Luminosities:
  - in $10^{32}$ - $10^{33}$ $cm^{-2}s^{-1}$ region for e-p
  - in $10^{30}$ - $10^{31}$ $cm^{-2}s^{-1}$ region for e-Au collisions
- 70% polarization degree for both lepton and proton beams
  - Longitudinal polarization in the collision point for both lepton and proton beams

# Main design line

**5-10 GeV static e-ring**      **up to 10 GeV injector**

**RHIC**

**e-cooling**

**EBIS**    **BOOSTER**

**LINAC**

**AGS**

The design is being developed involving scientists from
BNL, MIT-Bates, BINP (Russia) and DESY(Germany).

- The electron ring of 1/3 of the RHIC ion ring circumference
- Full energy injection using polarized electron source and 10 GeV energy linac.
- e-ion collisions are in one interaction point.
  But should allow for ion-ion collisions in two other IPs at the same time.
- The beams with matched electron and ion beam sizes at the IP.
- Longitudinal polarization produced by local spin rotators in interaction regions.

# Luminosity considerations

- Luminosity limitation comes from beam-beam effects and from interaction region magnet aperture:

$$L = f_c \frac{\pi \gamma_i \gamma_e}{r_i r_e} \xi_{xi} \xi_{ye} \sigma'_{xi} \sigma'_{ye} \frac{(1+K)^2}{K}$$

- Beam-beam limits (from world experience, RHIC operation experience and initial beam-beam simulation results):

  $\xi_e < 0.08$,    $\xi_i < 0.02$ (total from all collision points)

- From interaction region design :

  $\sigma'_i \leq 95 \, \mu rad$ and $K=1/2$ ($\sigma_y/\sigma_x$ beam size ratio; elliptical beams)

- $f_c = 28.15 \, MHz$   : 360 bunches in the ion ring, 120 bunches in the electron ring

# Basic beam parameters for e-p collisions

| | High energy setup | | Low energy setup | |
|---|---|---|---|---|
| | p | e | p | e |
| Energy, Gev | 250 | 10 | 50 | 5 |
| Bunch intensity, $10^{11}$ | 1 | 1 | 1 | 1 |
| Ion normalized emittance, $\pi$ mm.mrad, x/y | 15/15 | | 5/5 | |
| rms emittance, nm, x/y | 9.5/9.5 | 53/9.5 | 16.1/16.1 | 85/38 |
| beta*, cm, x/y | 108/27 | 19/27 | 186/46 | 35/20 |
| beam-beam parameters, x/y | 0.0065/0.00325 | 0.029/0.08 | 0.019/0.0095 | 0.036/0.04 |
| $\kappa = \varepsilon_y/\varepsilon_x$ | 1 | 0.18 | 1 | 0.45 |
| Luminosity, 1e32, cm$^{-2}$s$^{-1}$ | 4.4 | | 1.5 | |

No cooling
2 p-p IPs assumed

Cooling needed
No p-p IPs allowed

# Basic beam parameters for e-Au collisions

| | High energy setup | | Low energy setup | |
|---|---|---|---|---|
| | Au | e | Au | e |
| Energy, Gev/u | 100 | 10 | 100 | 5 |
| Bunch intensity, $10^{11}$ | 0.01 | 1 | 0.45 | 1 |
| Ion normalized emittance, $\pi$ mm, x/y | 6/6 | | 6/6 | |
| rms emittance, nm, x/y | 9.5/9.5 | 54/7.5 | 9.5/9.5 | 54/13.5 |
| beta*, cm, x/y | 108/27 | 19/34 | 108/27 | 19/19 |
| beam-beam parameters, x/y | 0.0065/0.00325 | 0.0224/0.08 | 0.0065/0.00325 | 0.02/0.04 |
| $\kappa = \varepsilon_y/\varepsilon_x$ | 1 | 0.14 | 1 | 0.25 |
| Luminosity, 1e30, cm$^{-2}$s$^{-1}$ | 4.4 | | 2.0 | |

Electron cooling of Au beam is required to achieve and maintain listed Au emittance values

# Electron ring issues

- **Flexible emittance control.**
  - The lattice should provide variable electron emittance in the range:
  - 30-130 mm.mrad in dependence on collision energy setup.
  - Chromaticity corrections and high dynamic aperture in all emittance range.
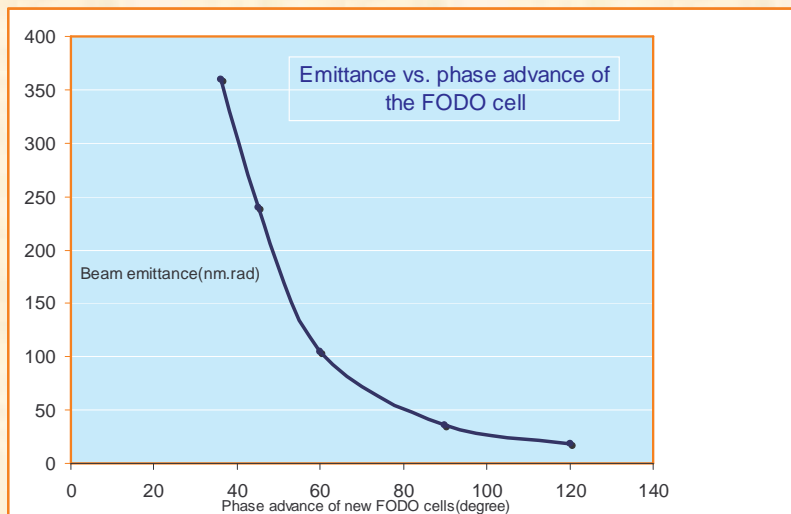
- **Synchrotron radiation power accommodation**
  - Total radiated power ~ 5 MW
  - Power load/m ~ 9.5 kW
  - (at the level of existing PEP B-factory)
  - Vacuum chamber design;

- **Variable ring circumference.**
  - $\Delta C$ up to 20 cm is needed to match the proton revolution frequency at different proton enrgies.

- **Polarization optimization.**
  - Minimization of depolarizing effect of spin resonances for electrons (HERA experience)
  - Self-polarization for 10 GeV positrons (~22min polarization time)



Emittance vs. phase advance of the FODO cell

Beam emittance(nm.rad)

Phase advance of new FODO cells(degree)

# Parameters of current e-ring lattice

| | ZDR1.0-10GeV 2003 | ZDR1.0-5GeV 2003 | e-RHIC 02(sup. B) | SLAC HER | KEKB HER |
|---|---|---|---|---|---|
| **Circumference(m)** | 1277.91 | 1277.91 | 958.65 | 2200.00 | 3016.26 |
| **Energy (GeV)** | 10 | 5 | 10 | 9 | 8 |
| **Bending radius(m)** | 81.0162 | 81.0162 | 58 | 165 | 88.95 |
| **Bunch Spacing (ns)** | 35.52 | 35.52 | 35.71 | 16.8/8.4/4.2 | 1.97 |
| **Bunch spacing(m)** | 10.65 | 10.65 | 10.71 | 1.26 | 0.59 |
| **Number of bunches** | 120.00 | 120.00 | 90.00 | 415/831/1658 | 5000 |
| **Bunch population** | 1.00E+11 | 1.00E+11 | 1.00E+11 | | 1.40E+10 |
| **Beam current(A)** | 0.45 | 0.45 | 0.45 | 3.00 | 1.1 |
| **Arc Cell** | FODO | FODO | FODO | FODO | 2.5π Cell noninterlea |
| **Harmonic Number** | 2028 | 2028 | 1169 | 3492 | 5120 |
| **RF frequency MHz** | 475.8 | 475.8 | 365.7 | 476 | 508.9 |
| **Energy loss/turn (MeV)** | 11.44 | 0.72 | 15.26 | 3.52 | 3.5 |
| | | | (+supper B) 21.26 | | |
| **Accelarting voltage(MV)** | 30 | 10 | 30 | 14 | 20 |
| **Synchrotron tune** | 0.04 | 0.034 | | 0.0449 | 0.011 |
| **Total rad. Power(MW)** | 5.13 | 0.32 | 9.57(with S.B) | 10.56 | 3.85 |
| **Syn. Rad. Power/m (KW) in Arc** | 9.63 | 0.60 | 18.78 | 10.19 | 6.89 |
| from normal bend | | | | | |
| Self-pola. Time at 10GeV(minutes) | 22.03 | 704.85 | 8.47 | | |
| **Emittance-x, no coupling (n m.rad)** | 30.7 | 93.8 | 65 | 49 | 25 |
| **Beta function at IP (cm) y/x** | 10./10 | 10./10 | 10./10 | 1.5/50 | 1./33 |
| **Round Beam size at IP(um)** | 38.73 | 67.08 | 57.01 | | |
| **Momentum compaction α** | 1.79E-03 | 9.12E-03 | | | 2.00E-04 |
| **Momentum spread** | 9.53E-04 | 4.76E-04 | 1.60E-03 | 6.00E-04 | 6.70E-04 |
| **Bunch length (cm)** | 1.72 | 3.2 | 2 | 1.1 | 0.4 |
| **S.R. damping time(x) (mS)** | 7.4 | 58.6 | 4.2 | 37.7 | 23 |
| | | | | | |
| **Beta tune Ux** | 30.579 | 17.808 | 27.48 | 24.62 | 44.51 |
| **Beta tune Uy** | 28.649 | 15.722 | 21.9 | 23.64 | 42.29 |
| **Natural chromaticity x,y** | 30nm: x=-61.80, y=-56.38 | 90nm: x=-44.86, y=-35.89 | x=-76, y=-53 | | |
| | | | | | |

# Injector system design

Developed by MIT-Bates group

5 GeV

160 MeV positrons

5-10min filling time

160 MeV electrons
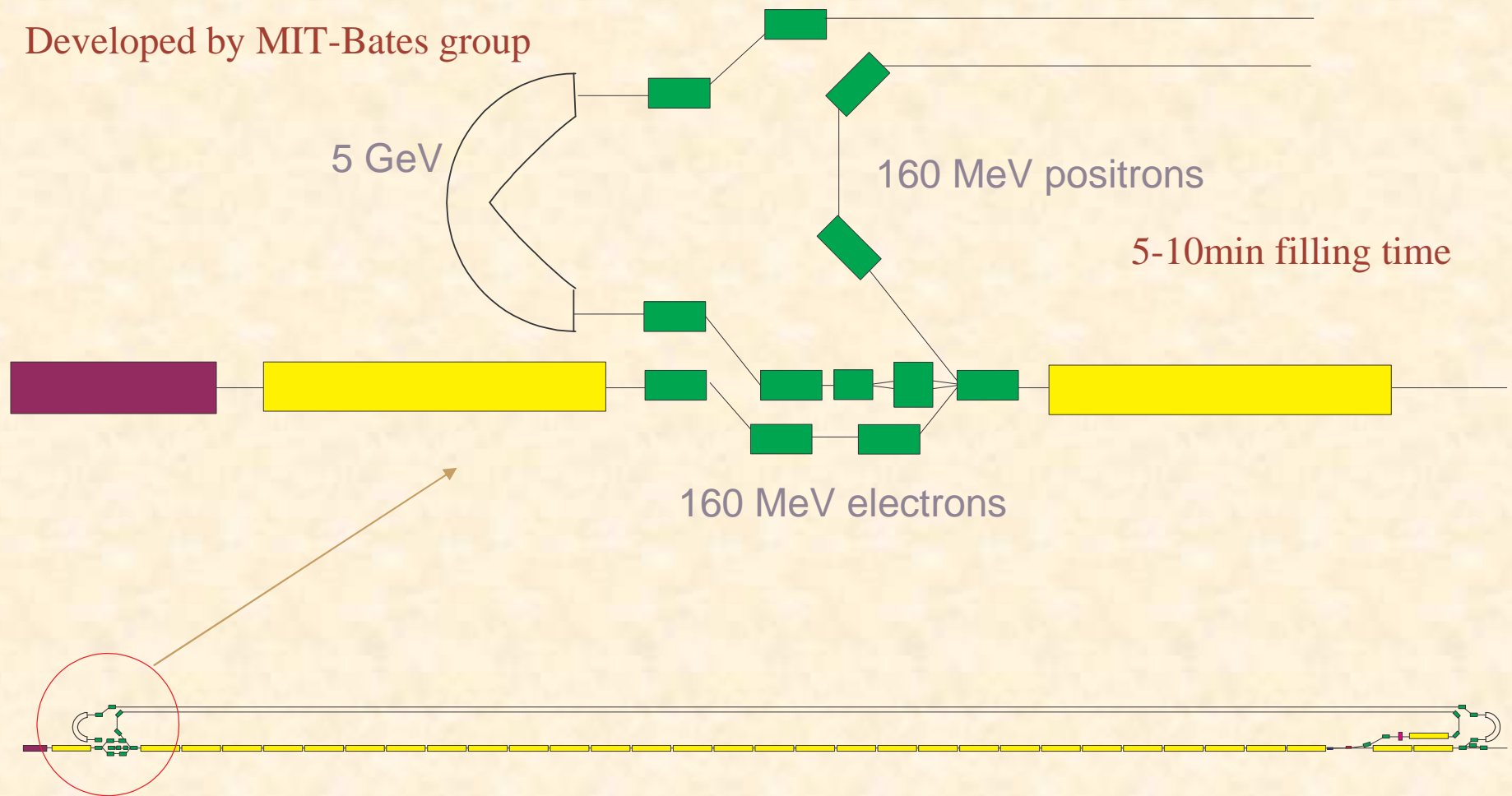
*Polarized electron source + 2x5 GeV acceleration linac + positron production system*

# Required ion ring upgrades

- **Increasing number of bunches ($n_b$) from 60-120 to 360 bunches**
  - Systems development needed:
    - Faster injection kicker (~20 ns risetime) OR
    - RF Manipulation (barrier bucket cavity and bunch merging) in RHIC
  - Physical limitations to be studied and overcomed:
    - Vacuum pressure rise, electron cloud. Remedies:
      - NEG coating; vacuum chamber baking; using solenoids; beam scrubbing;
    - Long range beam-beam effects (issue for beam separation scheme).
    - Abort system upgrade
    - Cryogenic load; Beam instabilities; RF Loading

- **Beam cooling**
  - Transverse electron cooling for Au to reach the required emittance ( and luminosity) value.
  - Transverse cooling for protons at energies below 150 GeV needed.
  - Longitudinal cooling to reach shorter rms bunch length (<20cm).

# Interaction region scheme

- Horizontal e-ion beam separation; vertical ion-ion rings separation.
- Head-on collisions.
- The scheme avoids parasitic beam-beam collisions.
- Flat e-ring suitable for polarization preservation.
- Synchrotron radiation issues:
  - l  detector background
  - l  IR magnet protection
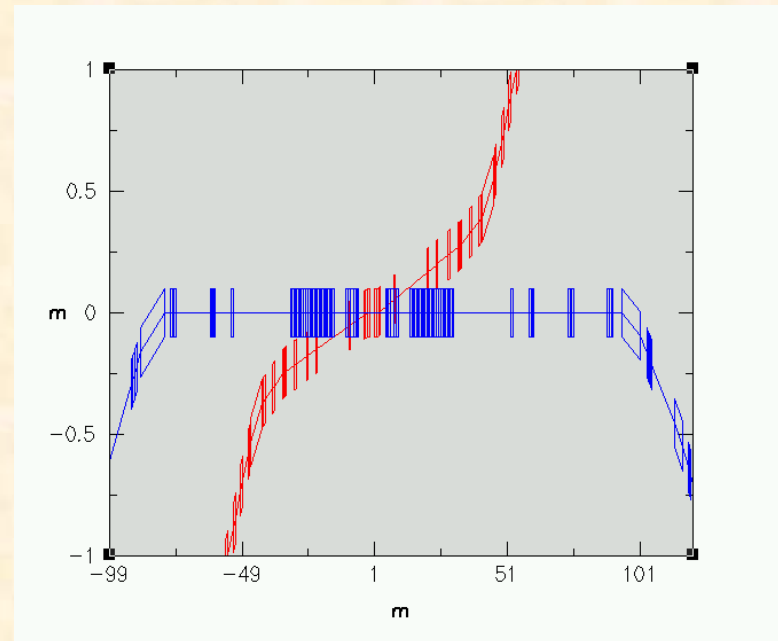


Interaction region design appeared to be crucial subject.
Puts limits on the luminosity that can be achieved.
C.Montag's talk in afternoon.

# Electron beam polarization
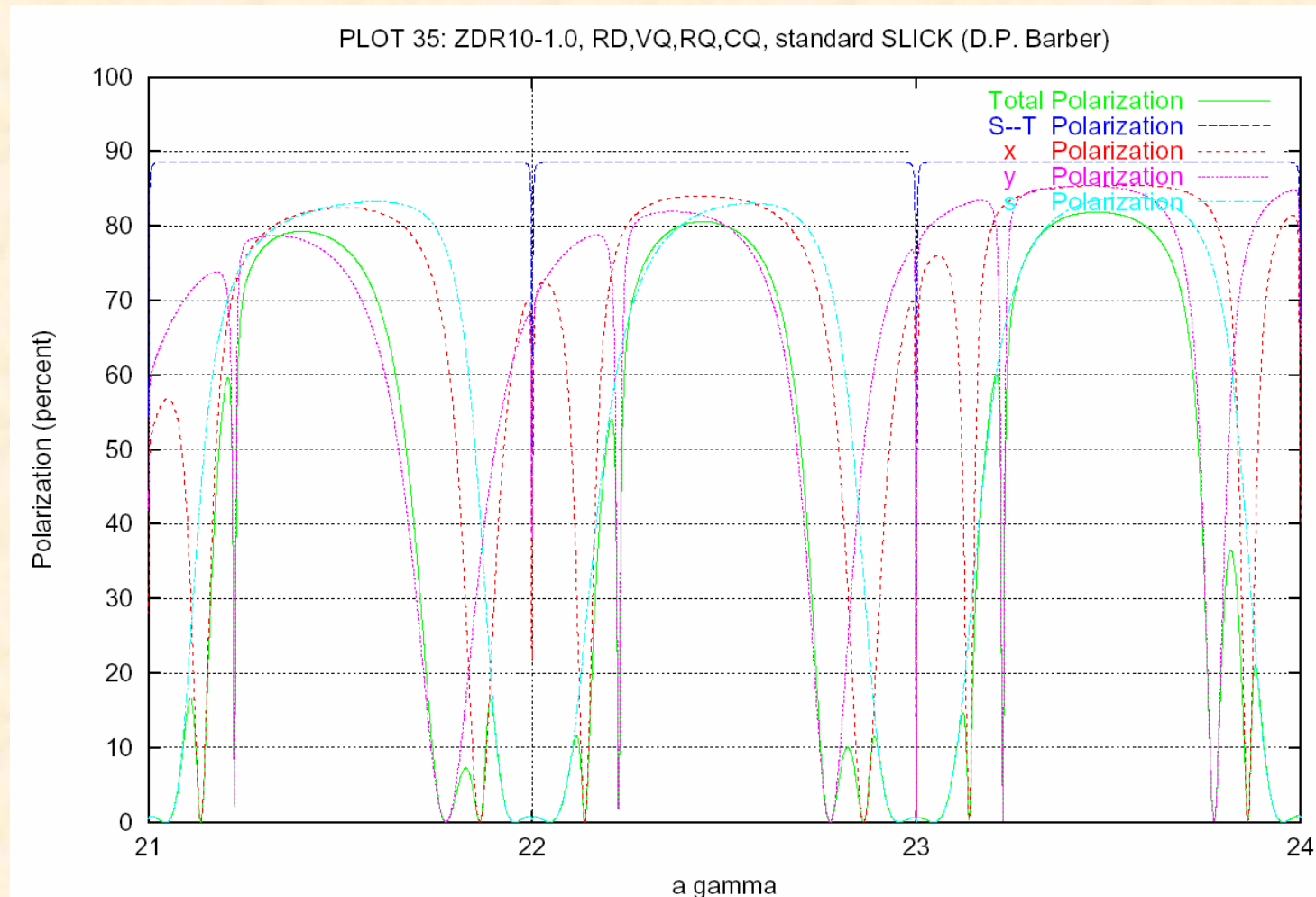


Depolarizing spin resonances are present due to betatron motion and closed orbit errors.
Correct choice of betatron tunes; Spin resonance harmonic correction system (HERA like)

# Spin rotators

**e-ring:** solenoidal spin rotator -> simplest solution (BINP design)

- Perfect longitudinal polarization at 7.5GeV ~15% reduction at 5 or 10 GeV.
- Spin transparency conditions on optics
- ~50 Tm longitudinal field integral at 10 GeV
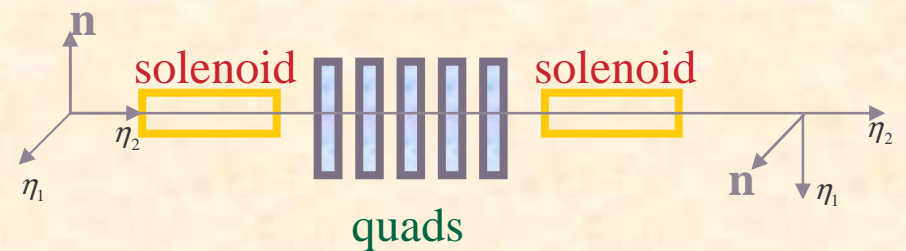


**p-ring:**

Helical spin rotator like being used already at two RHIC experiments
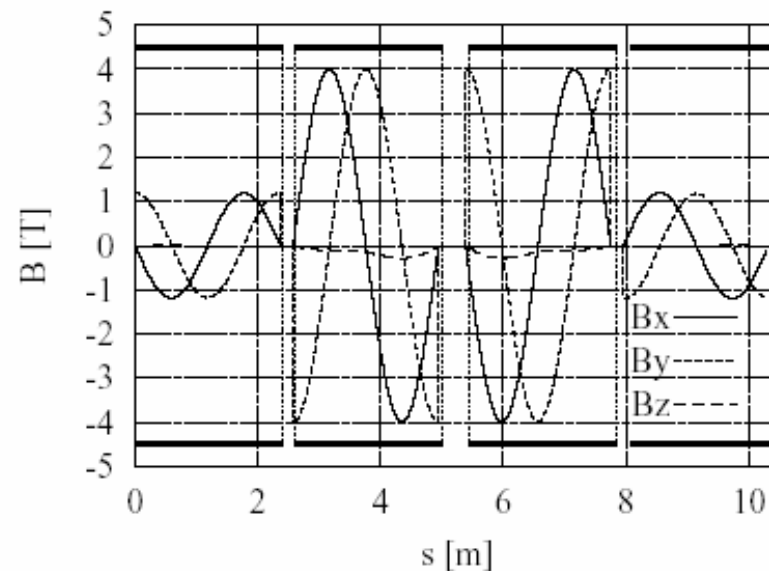
# Linac-Ring Option

Electron beam is brought to collision point directly from
superconducting energy recovery linac.
500mA electron current; 10 GeV energy.
Possible design for eRHIC is under consideration
(I.Ben-Zvi's group)

- No beam-beam limitation for electron beam
- Simpler polarization handling
- Simpler interaction region design

Things to be resolved:

- Development of high current polarized electron source needed
- Development of energy recovery technology for high energy and high current beams

# Summary

- The main design is based on the construction of 5-10GeV electron ring and 10 GeV linac for full energy injection.

- Polarized e-p and unpolarized e-ion beam collisions in the center of mass energy range of 20-100 Gev and at luminosities above $10^{32}$ cm$^{-2}$s$^{-1}$ for e-p and $10^{30}$ cm$^{-2}$s$^{-1}$ for e-Au collisions.

- The collider design could be realized using the present level of the accelerator technology.

- Major challenges: increasing ion current (number of bunches) in ion ring and synchrotron power load accommodation for electron ring.

- Alternative design developments:
  - Using energy recovery electron linac (without the e-ring)
  - Self-polarizing ramping e-ring (without full energy linac and polarized source).

- Project ZDR in January 2004